Chapter 5
Entrepreneurship and Government in U.S. High-Tech Policy

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5.1 Introduction

The U.S. has long been considered a leader in high-tech industries. Among the factors identified as creating favourable circumstances for innovation are: a culture supportive of risk-taking and entrepreneurship, abundant availability of venture capital, low costs of starting a business, and diverse forms of government support despite the absence of an overarching high-tech policy. Comparative studies in the national innovation systems (NIS) and the varieties of capitalism (VoC) literature (see Werle, Chap. 2) often describe the U.S. as the prototype of a laissez-faire economy that is particularly apt to spawn radical innovations. A closer look reveals, however, historical variations in the relative importance of market forces and government intervention. This flexible and differentiated interaction is seen as one of the distinct features of the U.S. innovation system and its success.

The decisive American lead over other industrialised nations in the post-World War II era has weakened recently. Not only has the U.S. lost a large number of manufacturing jobs during the past decade, it also suffers from a trade deficit in advanced technology products, amounting to $81.8 billion in 2010 (U.S. Census Bureau 2011). The deficit was particularly high in information and communications, as well as opto-electronics and life sciences. In 2008, six OECD member states spent a higher share of their GDP on R&D than the U.S., whose gross expenditures on research and development were 2.8% of its GDP (OECD 2010). And in a recent report benchmarking the global innovation-based competitiveness of the EU and the U.S., the Information Technology and Innovation Foundation (ITIF) asserted that the U.S., while still ahead of the EU overall, was ranked sixth behind Singapore, Sweden, Luxembourg, Denmark and South Korea. Alas, during

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the last decade, the U.S. had made the least progress in improving its competitiveness (R. D. Anderson and Andes 2009).

This slipping performance is the outcome of several domestic and international developments. Other countries have increased their efforts and developed considerable presences in high-tech industries, as illustrated, for example, by the emergence of a European aircraft industry, the strength of European and Asian countries in high-speed trains, and the emergence of Asian nations as formidable players in semiconductor manufacturing, consumer electronics and communication technologies. At the same time, U.S. multinational firms have shifted some of their production, including related research and development, to developing and emerging nations. With an increasing share of services in GDP, the U.S. is facing new challenges in sustaining innovation. Some services, particularly highly personalised services, may offer only limited innovation opportunities; some, such as advanced electronic commerce services, require new forms of cooperation and coordination among players, and therefore may not thrive in a laissez-faire environment; and others, such as many internet-based services, face daunting challenges in finding a sustainable revenue model. As international markets for services are less open than those for goods, the U.S. economy, with its high share of services, is in a difficult position (for which the structural current account deficit is but one indication). U.S. policy has created additional domestic hurdles for high-tech industries, for example, by limiting stem cell research. Although several other factors were at work, the economic crisis of 2008 can also be interpreted as a sign of the potential difficulties faced by a large, service-based economy in sustaining innovation, especially when mixed with a laissez-faire market model. Complicated derivatives, once described by Warren Buffett as “financial weapons of mass destruction” (Berkshire Hathaway 2002), can be seen as financial high-tech innovations whose potential risks and effects on the economy are poorly understood.

In response to lingering concerns about lackluster innovation performance, aggravated by the economic crisis of 2008, the Obama Administration released a Strategy for American Innovation (White House 2011). It is the first attempt at formulating a comprehensive high-tech and innovation policy agenda in decades, combining funding for strategic research areas, promotion of markets and entrepreneurship, and measures to catalyse national priorities in areas such as renewable energy, energy efficiency and health IT. Although many implementation details and actual effects remain to be seen, the strategy reflects increasing disappointment with the innovation performance of the U.S. economy and a backlash against laissez-faire policy. However, given the number of rivaling interests and possible veto players, the U.S. will most likely not embrace an interventionist industrial policy, but rather steer a middle course by recalibrating the relative roles of the public and the private sectors.

The first three sections of this chapter discuss the basic elements of U.S. high-tech policy, the strengths and weaknesses of the historical system, and current forces and initiatives that are transforming it. Sections 4–7 focus on the information and communication technology (ICT) sector, which has historically been central to high-tech policy and continues to be one of its cornerstones. Section 8 discusses the challenges faced by U.S. high-tech policy and the complexity of effective coordination in a changing global environment for technology industries. Main points of the chapter are synthesised in the conclusions.

5.2 The U.S. Innovation System

Notwithstanding strong beliefs in unfettered markets, government plays an important role in U.S. innovation policy (Block and Keller 2011). This role has changed over time, but it continues to be multi-faceted and distributed. It is this differentiated, parallel and sometimes redundant nature of efforts that has historically fuelled the dynamism of the U.S. innovation system (Alic et al. 2003). For reasons external and internal to the U.S., this approach currently faces considerable stress. Some of these weaknesses, such as the imbalance of military and civilian research funding, were already visible during the 1970s. Others emerged more recently with the changes in the global economy and the political repositioning of the U.S.. A brief synopsis of the main features and the evolution of this system will help in putting these challenges into context.

Prior to World War II, the states played a proactive role in innovation policy by funding public higher education and extension activities (i.e., knowledge transfer to practice) of many public universities, prominent among them the “land grant” universities (Mowery and Rosenberg 1993). During that time period, research facilities were established in universities and first informal linkages between universities and industry were developed. The federal government assumed only a secondary role in non-agricultural research support. World War II and the subsequent Cold War changed this picture quite dramatically. Largely motivated by national security concerns rather than an economic strategy, the role of the federal government greatly expanded and superseded state involvement. Table 5.1 shows that spending on R&D increased from 1.51% of GDP in 1955 to a peak of 2.82% in 1965, thereafter fluctuating between a low of 2.18% in 1975 and an estimated 2.75% in 2008, the most recent year for which data was available. The data also shows a fundamental shift in the relative importance of various sources of funds. In 1955, government spent $3.6 billion (57.4%), industry $2.5 billion (40.2%) and others, including universities, only $0.2 billion (2.5%). Government’s share increased to 65.1% by 1965, when it started a steady decline. Total R&D expenditures for all sources were $398 billion in 2008, to which government contributed 26.1%, industry 67.4% and other sources 6.6%.

During the height of the Cold War, a vast share of more than 80% of federal spending on R&D was defense-related. Although military R&D funding declined somewhat, its share remains high. After dropping to below 50% in the late 1970s, it increased again to nearly 70% during the Reagan Administration. In 2008, the share of Department of Defense research spending stood at 57.3%, which constitutes a lower boundary, as other agencies also contribute to military R&D funding (NSF

Table 5.1 Sources of U.S. R&D funds

Year	Federal US$ 10^6	Industry US$ 10^6	Other US$ 10^6	Federal (%)	Industry (%)	Other (%)	% of GDP	Done by federal	Done by industry	Done by other
1955	3,603	2,522	156	57.4	40.2	2.5	1.5	15.5	73.9	10.6
1960	8,915	4,516	280	65.0	32.9	2.0	2.6	13.1	76.6	10.2
1965	13,194	6,549	511	65.1	32.3	2.5	2.8	15.6	70.0	14.4
1970	14,984	10,449	839	57.0	39.8	3.2	2.5	15.8	68.8	15.4
1975	18,533	15,824	1,314	52.0	44.4	3.7	2.2	15.6	67.8	16.6
1980	29,986	30,929	2,310	47.4	48.9	3.7	2.3	12.4	70.4	17.2
1985	52,641	57,962	4,068	45.9	50.5	3.5	2.7	11.4	73.5	15.1
1990	61,610	83,208	7,175	40.5	54.7	4.7	2.6	10.3	72.2	17.5
1995	62,969	110,871	9,786	34.3	60.4	5.3	2.5	9.2	71.9	18.9
2000	66,417	186,136	14,746	24.8	69.6	5.5	2.7	6.7	75.6	17.7
2005	93,817	207,826	20,461	29.1	64.5	6.4	2.6	7.6	71.0	21.4
2008[a]	103,696	267,847	26,073	26.1	67.4	6.6	2.8	6.8	74.0	19.2

Source: NSF (2010), Appendix Tables 4–3 and 4–7
[a]2008 data preliminary

2010, pp. 4–22). Mowery and Rosenberg (1993) were concerned that this high share of defense R&D put the U.S. economy at a disadvantage compared to industrialised peer nations such as Japan and Germany, countries that dedicated a much higher share of research resources to civilian projects. Although it funded a large portion of research, the U.S. government was not the main locus where it took place. The last three columns of Table 5.1 show that most of the research was performed by private industry and universities. The share of federally performed R&D has declined steadily since the 1970s. It was picked up by universities and projects carried out jointly with federal labs, which are included in the "other" column (NSF 2010).

Since the late 1940s, several distinct periods can be distinguished. In their concise overview of the contribution of government to U.S. innovation activity, Block and Keller (2011) identify three turning points: (1) the major expansion in the late 1940s and 1950s, (2) the decentralization of the federal research support system until the 1980s, and (3) a continued proactive role of government initiatives during the era of market fundamentalism until the economic crisis of 2008. A first major expansion of resources dedicated to R&D happened during and immediately after World War II. This was an extraordinarily productive time with significant breakthroughs both in military and civilian technology (e.g., the computer, the transistor, nuclear power, radar and semiconductors), albeit with very high government funding. During this time, government capacity to pursue scientific work was expanded with the creation of a network of federal laboratories, such as Los Alamos, Lawrence Berkeley, Oak Ridge and Sandia, which had their roots in the Manhattan Project's atomic research programme. Many of the initiatives funding basic research were entrusted to the National Science Foundation (NSF) in 1950.

In the late 1950s, this system was further differentiated and decentralised (Block and Keller 2011, p. 8). Early Russian successes in the space race were answered with the creation of several new agencies, including NASA (National Aeronautics and Space Administration) and DARPA (the Defense Advanced Research Projects Agency). President Kennedy formed the Office of Science and Technology to provide analysis and recommendations mostly related to space technology. In 1976, Congress renamed the office to the Office of Science and Technology Policy (OSTP) and gave it a broader mandate. At the same time, spin-offs from large corporations and universities emerged as a new model for commercializing research. DARPA took advantage of this new organization of the research and innovation process by instigating competition between start-up firms, which stood in contrast to the large and expensive corporate research labs that had dominated earlier. Established firms and their research activities were forced to respond to these challenges with increased efforts of their own. Unlike NSF, DARPA did not rely on elaborate peer review of grant applications, which allowed the agency to fund projects in an agile and flexible fashion (Alic et al. 2003).

A third turning point occurred in the 1980s. Despite the emerging market fundamentalist political attitude, Block and Keller (2011) argue government continued to take a proactive, if not as visible role. The increasing trade deficit provided the backdrop to a discussion of how an active technology and science policy could be used to narrow the deficit. Rival nations such as Japan and Germany had been able to catch up with American firms in several areas, which had negative effects on the U.S.'s foreign trade balance. After the Keynesian consensus had crumbled during the stagflation period of the 1970s, innovation promotion had become rooted in a strong trust in market forces. Two legislative initiatives in 1980 sought to improve technology transfer and commercialization. The Stevenson-Wyler Technology Innovation Act of 1980[1] intended to encourage research collaboration between federal and other institutions and required the federal laboratories to strengthen technology transfer efforts. The Bayh-Dole Patent and Trademark Amendments Act of 1980[2] permitted recipients of federal grants to file patents on the results of such grants and to award exclusive licenses to other parties. An underlying assumption was that such stronger protection would accelerate technology commercialization. Whereas other countries have attempted to emulate the Act, the empirical evidence assessing its effects is weak. Some analysts claim it facilitated the breakthrough of the biotechnology industry,[3] but empirical research has found only small or even negative impacts (Mowery et al. 2004; Rafferty 2008).

Among the most successful programmes established during the 1980s were the Small Business Innovation Research (SBIR) Program and the Small Business Technology Transfer (SBTT) Program. Signed into law by President Reagan in 1982, SBIR made permanent an NSF pilot programme started under Jimmy Carter. Administered by the U.S. Small Business Administration (SBA) Office of Technology, the programme required that government agencies with large research budgets

[1] Stevenson-Wyler Technology Innovation Act of 1980, Public Law 96–480, October 21, 1980. .

[2] Bayh-Dole Patent and Trademark Amendments Act of 1980, Public Law 96–517, December 12, 1980.

[3] E.g., "Innovation's Golden Goose," The Economist, December 14, 2002, p. 3.

dedicate a percentage of their funds to small for-profit start-up companies. In 2010, 11 federal government departments participated in SBIR and five in SBTT, awarding approximately $2 billion to small high-tech companies. Funding of up to $150,000 is available during the initial Phase I of projects. If successful, up to $1 million may be awarded during Phase II. The vast majority of empirical studies confirm that the programme has been successful in stimulating innovation in high-tech start-up businesses (Link and Ruhm 2009; Link and Scott 2010; Audretsch 2003), although a few authors reach more skeptical conclusions (Wallsten 2000). Ambitious programmes, such as the Advanced Technologies Program (ATP) failed, often due to agency conflicts (Negoita 2011). Others, such as the decentralised Manufacturing Extension Program, did not reach their intended profile.

5.3 The Rejuvenation of High-Tech Policy

Faced with a widening trade deficit, President Bush signed the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007 (short America COMPETES Act), a comprehensive set of initiatives to improve the international competitiveness of the U.S. The Act was reauthorised in 2010 and signed into law in January 2011.[4] Its provisions strengthen the role of the federal agencies supporting research into advanced technologies. This includes increased funding, new organizational units to better promote innovation, prizes for innovation, and improved dissemination strategies for scientific information. For example, Section 601(a) directs the Secretary of Commerce to establish an Office of Innovation and Entrepreneurship "to foster the innovation and commercialization of new technologies, products, processes, and services to promote productivity and economic growth in the United States". Moreover, the Act establishes to better coordinate activities that support education in science, technology, engineering and mathematics (STEM).

A further major rejuvenation of high-tech policy was launched by the Obama administration in its Strategy for American Innovation (White House 2011). A $780 billion stimulus package was passed in response to the 2008 economic crisis.[5] As part of this package, funding for the national institutes, including NSF and NIH, was substantially increased, infrastructure projects were funded, and large amounts of money were channelled into strategic initiatives. However, the Administration also initiated a coherent overhaul of the fragmented system of high-tech policy. Orchestrated by the overarching motto, expressed by President Obama in his

[4] America COMPETES Reauthorization Act of 2010 or America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Reauthorization Act of 2010, Public Law No: 111–358, January 4, 2011.

[5] Authorised in the American Recovery and Reinvestment Act (ARRA) of 2009, Pub. L. No. 111–115, Feb. 19, 2009.

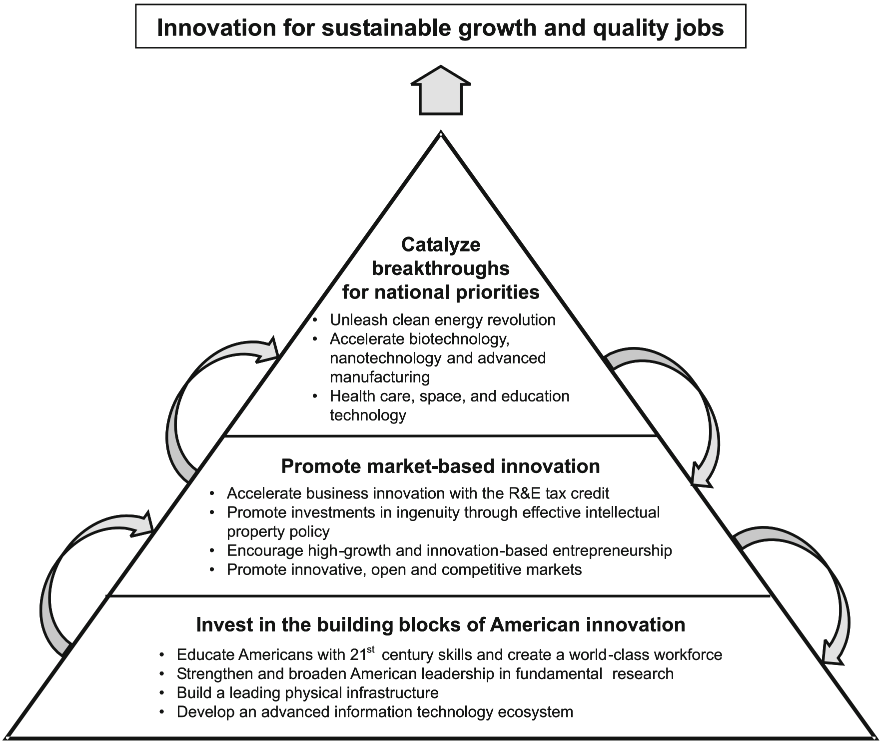

Fig. 5.1 Strategy for American innovation. Source: White House (2011), http://www.whitehouse.gov/innovation/strategy/executive-summary

January 2011 State of the Union address, to "out-innovate, out-build, out-compete, and out-educate" the rest of the world, a broad range of initiatives was designed. The Innovation Strategy contains three major components (see Fig. 5.1): (1) investment in the building blocks of American innovation, (2) the promotion of competitive markets and entrepreneurship, and (3) measures that catalyse breakthroughs for national priorities. The strategy recognises that the bubble economies of the 1990s (built on highly inflated information technology stocks) and of the early 2000s (driven by inflated housing prices and an associated financial services industry) were unsustainable forms of economic growth that need to be replaced with more lasting achievements. It walks a middle ground between massive expansion of government intervention and reliance on unfettered markets, casting government as a convener and a facilitator of robust economic growth.

Investment in the building blocks of American innovation was boosted with $18.3 billion in research funding. In accordance with longer-term goals of increased funding, a doubling of the budgets of the National Science Foundation (NSF), the Department of Energy's Office of Science, and the National Institutes of Standards and Technologies (NIST) was set. Investment in these agencies is seen as a critical input to the development of "industries and jobs of the future, such as the convergence of bio, info, and nanotechnologies" (White House 2011, p. 10). A second long-term goal is to increase economy-wide public and private investment in R&D to more than three percent of GDP. Lastly, the strategy proposes to make the research and experimentation tax credit permanent, a $75 billion relief to businesses. Additional research funding is combined with several initiatives to enhance American education, including the goal to reclaim the global top position in the number of college graduates by 2020, an increase of $200 billion in scholarships over a 10-year period, and the utilization of online learning in continuing, post-secondary education (White House 2009). A third key aspect of this building block is investment in physical infrastructure. Roads, rail, the electricity grid and air traffic systems are in need of massive modernization, a goal that had not been supported well by the liberalization policies since the 1970s.The last component, which will be discussed in more detail in the next section of this chapter, is the development of an advanced information technology ecosystem (White House 2009).

Measures to promote market-based innovation are a second major element of the strategy. Here the administration lists a broad set of aims, ranging from an extension of the Research and Experimentation (R&E) Tax Credit to trade agreements that intend to help double U.S. exports by 2014. Measures to support innovative entrepreneurs include better access to credit, faster patenting, and the Startup America Partnership, which is branded as an "initiative to celebrate, inspire, and accelerate high-growth entrepreneurship throughout the nation."[6] Four measures are packaged to assist start-up companies in crossing the "valley of death", which separates the early phases of business development from a sustainable business model: (1) additional access to venture capital in the form of government matching funds ($2 billion), (2) a simplification of regulations affecting small businesses, (3) mentoring for founders of start-up companies, and (4) tax relief for small businesses. Complementing these drivers of high-tech growth is additional support for innovation hubs, "large, multi-disciplinary, highly-collaborative teams of scientists and engineers working to achieve a specific high priority goal" (White House 2009, Appendix C). For example, Department of Energy innovation hubs have been established for efficient building technology, liquid fuels from sunlight, and the modeling and simulation of nuclear reactors.

The final layer of the national innovation strategy seeks to advance five national priorities: unleashing of a clean energy revolution; acceleration of biotechnology, nanotechnology and advanced manufacturing; breakthrough space capabilities and applications; breakthroughs in health technology; and significant advances in educational technology (White House 2011). Several of the initiatives are modelled after DARPA, widely seen as one of the most successful federal agencies in stimulating high-tech industries. The Advanced Research Projects Agency-Energy

[6] See http://www.whitehouse.gov/issues/startup-america.

(ARPA-E) is the Department of Energy's vehicle to promote clean, secure and independent energy technologies, whereas the Advanced Research Projects Agency-Education (ARPA-ED) is supposed to spearhead similar high-tech projects in the education field. In the health area, a new National Center for Advancing Translational Sciences designed to foster new forms of knowledge transfer between research labs and clinics, was proposed by the National Institutes of Health. A National Nanotechnology Initiative (NNI) carries hopes of enabling revolutionary breakthroughs in nano-electronics. At first glance, these priority areas resemble traditional forms of industrial policy. However, the role of government is conceptualised differently, often as the catalyst, the convener of networks of researchers and of public-private partnerships. The hope is that many of the regulatory and governance issues that arise, for example, in the sharing of medical data, will be addressed by new forms of networked governance (Berejka 2011).

The next four sections of the chapter discuss the ICT sector, which occupies a central position in U.S. high-tech policy. It can be used to illustrate key elements of U.S. policy, particularly, the diversity of agents, their interaction, and the expected and unexpected emergent properties of the entire system.

5.4 The Evolution of U.S. ICT Policy

The structure and performance of the U.S. ICT sector are the outcome of the co-evolution of technology, institutions (including public policy), business strategy, and user decisions. Decisions in each of these areas influenced the further development of coupled realms. Technological decisions affected subsequent policy options and choices; business strategy was enabled by technology developments and public policies; and public policy shaped technology and business strategy. This interaction had sometimes beneficial and sometimes undesirable or unintended consequences. Decisions in each of the realms constrained subsequent options in the others, thus generating forms of path dependency. These processes unfolded in the various segments of the ICT sector, most importantly in components (e.g., semiconductors, microelectronics and optoelectronics), computing and devices (e.g., mainframes, PCs, tablet computers, mobile handsets, and TV sets), networks and network services (e.g., fiber optical networks, mobile communications networks), software to operate the physical networks and devices (e.g., TCP/IP, DOCSIS, Android), as well as applications and end-user services. Not only are these activities high-tech industries in their own right, with a high share of R&D expenditures and high knowledge intensity, they are also important components of high-tech policy directed towards other sectors. ICTs are general purpose technologies that permeate an increasing number of other economic and social activities. By enabling smart appliances and smart grid technology, they are critical for increased energy efficiency. ICTs can reduce the environmental impact of transportation. They facilitate health services and are an indispensible element of advanced manufacturing technologies. At the same time, ICT components are embedded in products and services that are, per se, not considered "high-tech," such as networked refrigerators and other appliances.

High-tech policy has affected and continues to affect all these segments, but it does so in different ways. The configuration of this system has significantly changed since World War II. Historically, ICTs were engineered to provide a narrow range of services. For example, the telephone system was designed to provide high-quality, voice-grade service. Early data communication networks were engineered to support communication between computers. Even the predecessors of computers were designed for relatively specific uses. This gradually changed with the diffusion of digital technology from computing to devices and communication networks. As analog technology was replaced by digital technology, former industry boundaries started to blur. Modern ICT can be seen as layered systems in which physical networks of nodes and communication links enable the configuration and delivery of services and applications (Fransman 2010). Convergence has eliminated many historical boundaries between ICT subsectors with ambiguous effects on industry structure. On the one hand it resulted in considerable industry consolidation. On the other hand, it also coincided with new forms of differentiation and specialization, as illustrated by the vibrant and diverse application market segment.

A deeper understanding of U.S. ICT policy requires examining three aspects of this system: (1) policies toward components and hardware, (2) policies towards networks and basic services, and (3) policies affecting enhanced services and applications. These areas are often complementary to each other. Periods during which these areas were aligned with each other and periods when they were misaligned are visible during the past decades. Tensions have risen because components and hardware, data communications, as well as software and applications, are generally organised as competitive, unregulated industries, whereas networks and basic services have historically been regulated. The internet straddles these areas. Evolving from the unregulated data communications environment, it benefitted from the regulations governing traditional telecommunication networks. The U.S. ICT innovation system has repeatedly proven adaptive to respond to forms of misalignment but often only with considerable friction and delay.

5.5 Computing, Components, and Networking Protocols

Technical advances in components, hardware and protocols were more directly influenced by government actions than any other ICT market segments. During the formative years of these industries and through the height of the Cold War, military public procurement and research funding were primary instruments to promote innovation. More recently, indirect measures such as tax incentives, the facilitation of collaboration, and a strengthening of intellectual property have gained in importance. Government policy had a most decisive effect on the development of computing, was a catalyst in the development of software and the design of protocols to link computers, and was least influential in industries producing components such as semiconductors. The co-evolution of policy, technology and business strategy until the 1990s is documented elsewhere (e.g., Langlois 2002; Ruttan 2006; Flamm 1988). This section draws on this earlier work and supplements it with a brief look at recent developments.

Computing benefited directly from military procurement. During World War II, the military needed technology to aid in the calculation of artillery range tables. The Army Ballistics Research Laboratory (BRL) risked a bet on a new technology by commissioning the development of the first digital computer, the Electronic Numerical Integrator and Calculator (ENIAC), by researchers at the University of Pennsylvania (Ruttan 2006, p. 92). A new computing architecture, anticipated by several researchers and more fully developed by John von Neumann, who was involved in the computer-intensive Manhattan Project, logically separated instructions from the processing of operations, thus laying the groundwork for a separate software industry. A big boost for the commercial computing industry resulted from the funding by the U.S. Air Force of the Semi-Automatic Ground Environment (SAGE) system, a computerised air defense system (Ruttan 2006, p, 95), which in turn was an outgrowth of projects funded by the U.S. Department of Defense. With the emergence of minicomputers and eventually the microcomputer or personal computer (PC), commercial development and demand by the private sector became the main driving force behind further innovation. The rapid price decline in computing is an outcome of the open, modular design of the PC, which allowed many firms to pursue solutions to problems simultaneously, "leading to a rapid trial-and-error learning" (Langlois 2002). The shift to private sector activity was further accelerated by the migration to notebook computers, tablets, mobile devices, and advanced entertainment devices, such as internet-enabled TV sets and game consoles.

Beginning in the 1950s, transistors, and later integrated circuits, replaced vacuum tubes and contributed to the rapid decline in costs of digital technology. The transistor was invented by Bell Laboratories, whose researchers were working on a solution to handle the anticipated volume of telephone calls, for which the prevailing electromechanical switching technology was insufficient. The government was minimally involved in funding research leading to advancements in semiconductor technology. However, as a large buyer it contributed to and stabilised demand. Most importantly, the government bought from new specialised suppliers that could meet its needs, supporting new entrants such as Texas Instruments (TI) and Fairchild. These two companies were the birthplaces of the planar process of manufacturing integrated circuits. In part to avoid antitrust action, TI and Fairchild made their technology available to all new firms at relatively favourable licensing terms. The resulting open environment allowed other firms that were able to successfully commercialise the planar process to capture part of the innovation rents (Langlois 2002). U.S. leadership was challenged by Japan during the 1980s, in particular in the VSLI initiative. In response, SEMATECH (Semiconductor Manufacturing Technology) was established as a public-private partnership between the government and 14 private sector companies. Until the mid-1990s the public sector provided $100 million in annual matching funds to help develop processes and technologies beyond the capabilities of each individual participant. Experts are divided in their assessment of the success of SEMATECH, with some authors suggesting positive effects (Link et al. 1996; Grindley et al. 1994) but others arguing that public funding reduced private R&D expenditures (Irwin and Klenow 1996). In the mid-1990s the government withdrew funding and SEMATECH broadened its scope to international members, hence diluting the effect it might have on U.S. manufacturers.

Government also served as a catalyst for software and protocols needed to network computers, which eventually led to the emergence of the internet. Early funding of networking research was provided by the Department of Defense, which was interested in dual-use technology that could also serve civilian purposes (Langlois and Mowery 1996). Other federal agencies, such as the Department of Energy, NASA and NSF, were also involved. Of key importance in these early efforts was DARPA, an agency with relatively flexible spending rules that could fund projects bypassing lengthy peer reviews. The multitude of agencies and research centers led to duplicate and parallel efforts that allowed for simultaneous search in different directions, thus enhancing the chances of successful innovation (Langlois 2002). A standardised open networking protocol – TCP/IP – emerged from these initiatives and was deployed in ARPANET. In 1981, NSF started a parallel effort to network computer science departments in its Computer Science Network (CSNET). The agency's efforts to provide access to NSF's supercomputing centers and other computing-intensive research centers led to the deployment of NSFNET, an advanced network linking these centres, in 1985. NSFNET also used TCP/IP and eventually, beginning in 1990, ARPANET was subsumed into NSFNET. In the early 1990s, a gradual transition to private operation started, leading to the decommissioning and full privatization of NSFNET in 1995. Concern by researchers about the implications of privatization for higher education and research led to the formation of the Internet2 consortium. By 2011, the consortium had grown to include several hundred universities, corporations, and government agencies in the U.S. and in 50 other countries.[7] Since the 1960s, the role of the U.S. government in this realm of ICT has therefore changed from early catalyst to participant (and indirect funder) in broad-based joint private-public efforts.

5.6 Telecommunication Networks and Services

Much of high-tech policy seeks to shape the unregulated activities in the ICT system. Nonetheless, the older, more regulated telecommunications networks and services are an important aspect and help to understand some of the successes and

[7] See http://www.internet2.edu/about, retrieved 5 April 2011.

failures of U.S. ICT policy. Until the gradual migration to flatter IP-based architectures beginning in the 1990s, telecommunication networks were highly centralised and hierarchically organised. The mix of nodes and links varied with the relative cost of these two components. Much of the functionality (the "intelligence") of the services was embedded in the networks. Some of the finest research laboratories, such as Bell Labs, were operated by telecommunications companies. The centralised organization of the industry was supported by its monopolistic legal and regulatory framework. Based in a shared believe that telecommunications constituted a "natural monopoly," a situation in which technological and economic conditions are such that the lowest cost of serving demand is to pool all supply in one organization, the sector was operated by privately owned, government regulated firms. Eventually, however, technological and policy change heralded a new era in which the monopolistic organization gave way to more open markets and diverse technological platforms. In the U.S., this change unfolded over the course of several decades during which significant tensions and conflicts between the principles governing highly regulated telecommunications services and those governing essentially unregulated data communication services, as well as the boundaries of the organizations providing these services, had to be resolved (Brock 1981, 1994, 2003; Schneider 2001).

Telecommunications services, particularly voice communications, were historically treated as common carriers. Firms that are so designated have certain obligations (e.g., to provide services at non-discriminatory conditions) and rights (e.g., an opportunity to earn a fair return on the invested capital) that go beyond those of commercial firms. When data communications services became available, these common carriers were often slow in making the inputs needed for the new services, such as leased lines and modems, available. Some incumbents abused their strong market position to thwart competition. Consequently, the largely unregulated computing industry and users of the new services sought to address these problems in the public policy arena. Both antitrust and regulatory action were undertaken to mitigate the problems. In 1956, AT&T signed a Consent Decree with the U.S. Department of Justice in which it agreed to focus on common carrier voice services and to license technology related to data communications freely to other companies including the Unix operating system and the C programming language. Both technologies facilitated innovation in the emerging nascent ICT industries (Mowery and Simcoe 2002).

By the late 1970s, the telephone companies recognised the growth opportunities in data communications. At the same time, regulatory agencies were looking for ways to reduce the realm of regulated monopoly activities. Problems related to the presence of the dominant AT&T in both competitive and non-competitive markets were addressed with the break-up of the company in 1984. Again the agreement created a beneficial, but largely unanticipated, consequence by facilitating competition for leased lines and other data communications services and allowing companies providing these services to connect to local networks at regulated, reasonable conditions. The Telecommunications Act of 1996 furthered these causes by adopting a broad range of measures intended to expand competition to the last monopoly bastion – local exchange markets – and to support the further growth of data communications services and the internet in a market environment "unfettered by state and federal regulation."[8] As part of the Act's implementation, the Federal Communications Commission (FCC) continued the exemption of information service providers from per-minute access charges to local networks, which allowed the budding dial-up Internet Service Providers (ISPs) to connect modem banks to local networks at low, unmetered rates. As local phone services typically also were available at flat rates to end-users, dial-up internet service became available at relatively low, flat prices. Supported by these fortuitous conditions, dial-up internet diffused in the U.S. much faster than in other regions (Greenstein 2005).

In the early 1990s, there was widespread concern among U.S. policymakers that the country was losing the race toward modernizing communication networks. The National Telecommunications and Information Administration (NTIA) published a comprehensive report and strategy to improve sector performance and infrastructure investment (NTIA 1991). One of the key suggestions was to expand the realm of competition. Although not solely a response to this concern, the Telecommunications Act of 1996 followed that vision and established conditions to facilitate competition in local markets. This goal was initially implemented with stringent regulatory measures allowing resale of existing services and by requiring incumbent local exchange carriers (ILECs) to make network and service elements available on an unbundled basis at low, regulated prices. By the early 2000s, empirical evidence suggested that these measures had attracted new service-based competitors but had depressed incentives for new infrastructure investment. Confronted with the need to upgrade network infrastructure to broadband capacity and to roll-out next-generation networks, the FCC, in part prodded by the courts, reclassified the technologies capable of providing broadband access (cable modem service, Digital Subscriber Line service, broadband over powerline (BPL), and wireless broadband) from common carrier status to essentially unregulated information services (Bauer 2005; Bauer and Bohlin 2008).

These measures were designed to unleash the private sector's ability to invest and innovate in network infrastructure. They did increase investment but some of the hopes were not met. Rather, the weaknesses of a purely market-driven approach became more visible. For example, the expansion of networks to rural areas has been progressing slower than anticipated. Network upgrades are initially targeted to urban centers and market segments, such as mobile broadband, for which demand is high. One could argue that these policies have generated undesirable and unexpected consequences for ICT development by constraining further innovation dependent on more advanced network infrastructure. As in earlier cases, the

[8] The history of U.S. telecommunications policy reform is multifaceted and evolved in a highly complicated policy-making environment with many checks and balances between the main actors. This system facilitates challenges to existing policies but makes broad and sweeping overhauls more complicated. Compared to the European Union (EU), U.S. reform started much sooner but unfolded in a much more gradual and slower pattern.

policy-making system has responded to the perceived shortcomings. The Obama Administration has dedicated $7.2 billion of stimulus funding to support network upgrades and has launched additional initiatives to promote infrastructure modernization. For the first time since 1992, the U.S. has put together an ambitious National Broadband Plan, including a plan to expand wireless broadband. In contrast to the early 1990s, the measures proposed to overcome the perceived innovation shortfall entail an increase, rather than a decrease, in government involvement, including subsidies to roll-out networks to rural areas and public-private partnerships to accelerate adoption of new services (FCC 2010).

5.7 Software, Applications and Services

Hardware and the networks linking nodes and devices are intermediate technologies that enable applications and services, which are the ultimate sources of value generated by ICTs. In this vast and sprawling subsector, government policy was least present and other aspects of the U.S. innovation system are more critical in shaping the overall direction of innovation. The early investment in computer science departments probably had a positive effect on the development of a knowledge base in software development. The close relation between universities and business as well as the ease with which new firms could be established facilitated a vibrant culture of entrepreneurship. Many new firms were spun-off from universities and became the cores of entrepreneurial clusters such as Silicon Valley (California), Route 128 (Massachusetts), and the Research Triangle (North Carolina). Until the late 1960s, most software was bundled by computer manufacturers with the hardware and given away for free. This situation started to change slowly in the 1960s as more specialised software needs were met by products developed by software companies. When IBM announced in 1969 that it would start to unbundle and separately sell software, the industry received a further boost that sent it on a fast growth path. By the 1980s, software was on a steep growth path, but further change was in the make. The digitization of communication networks, and particularly the broad diffusion of the internet beginning in the mid-1990s, when the first browsers started to simplify its use, supported the emergence of new types of software-based services and applications on the edge of the network, epitomised in the concept of cloud computing. Growth in web applications was further propelled by the fast adoption of social media and wireless data communications and the mobile internet.

Government policy played a fairly limited direct role in these developments. At present, research funding by the military and federal agencies supports the development of advanced knowledge in computer science, simulation software, video games, and specialised areas such as health informatics or advanced graphics. In 2007, all federal agencies contributed slightly less than 2.5% of total R&D funding in the area of software and computer-related services (and only 0.5% to computer and electronic products) (NSF 2010). The remainder of R&D funds was generated by the private sector. The situation is similar in application markets, where the share of privately financed R&D may be even higher. Web applications use browsers to access tools such as online calendars, webmail, document processing, and electronic commerce functions. They first emerged in the fixed internet, where a number of open development frameworks were available. Like advanced communications systems, web applications consist of multiple tiers, often a presentation tier (the browser), an application tier (the functions, programmed in languages such as Java, PHP, or Ruby on Rails), and a storage tier (database).

Public policy has had an indirect – and most likely inadvertent – stimulating effect by promoting an open internet platform. Network and development platform openness has facilitated modular types of innovation and contributed to the vigorous growth of the application market. Open standards and open networks allow "permission-less" innovations at the edge of the internet, enabling entrepreneurs to design new applications without having to incur the potentially high transaction costs of negotiating with multiple network operators and service providers (Van Schewick 2010). The introduction of user-friendly mobile internet devices, such as the iPhone and other smart phones, has similarly boosted the market for mobile web applications. However, as the example of the iPhone and the rivaling open Android platform illustrate, openness is not a necessary condition for innovation. Developers have created numerous applications for both the walled-garden iPhone environment, controlled by Apple and based on its proprietary iOS mobile operating system, and the open Android environment, supported by Google. A key question is whether public policy makers ought to mandate network and platform openness. In the U.S., as in other countries, this has fueled an intense controversy conducted under the heading of network neutrality. Although this is primarily a discussion of communications policy principles, it also often refers to the effects of regulatory choices on innovation and U.S. competitiveness. In December 2010, the FCC adopted rules that proscribe certain minimal safeguards for open networks, but it promulgated less stringent rules for mobile network operators given the more urgent concerns about capacity constraints of mobile networks (FCC 2010).[9] However, this area continues to be in flux, with challenges to the FCC Order pending in appeals courts.

[9] Specifically, the FCC adopted three principles for fixed broadband access network operators: (1) no blocking of traffic and applications, (2) transparency of rules governing network management, and (3) non-discrimination, except in relatively limited scenarios, such as security concerns or binding capacity shortages, where network management is required. Mobile operators are subject to no blocking and transparency obligations but not the third one (FCC 2010).

5.8 Prospects and limits of high-tech policy

During the second half of the twentieth century, the U.S. ICT sector followed a strong performance trajectory, although considerable variations existed over time in the three subsectors. Toward the end of the millennium, competition from firms in other regions had considerably intensified and other nation's innovation policies had narrowed the gap between them and the U.S. In all three areas discussed above, global leadership became more contested and changed among the regions toward the end of the millennium. The time pattern varied between the subsectors. Until the 1990s, the U.S. could boast one of the most widely available and efficient network infrastructures, a considerable achievement given the size of its territory and the presence of vast rural areas with very low population density.[10] This strong performance became more lackluster during the 1990s. As other countries and regions revamped their historically monopoly-centric systems, they were able to unleash substantial efficiency improvements. In fixed broadband networks, South Korea and Japan pursued aggressive roll-out programmes, often orchestrated in public-private partnerships, followed by strict regulation, which put them in a global leadership position (Frieden 2005). Several smaller European countries, including the Netherlands, Sweden and Denmark, also adopted policies in support of rapid broadband deployment.

During the 1990s, as a consequence of enlightened policy choices, such as a Europe-wide standard for mobile communications (GSM), the European Union took the global lead in mobile voice communications. However, this position did not last and as mobile communications moved from voice toward a first generation of mobile data communications and mobile internet access, Japan and South Korea once again offered the most conducive environment. In the ongoing transition toward next-generation fixed and mobile broadband communications, the U.S. has regained a strong position (Falch et al. 2010). This position is stronger in mobile communications, where the country is arguably leading the charge toward new services and applications, and is somewhat more modest in next-generation fixed networks, where the weaknesses of a purely market-driven model have become visible. For example, while investment in urban areas has been strong, network upgrades in rural and sparsely populated areas are slower than anticipated. Furthermore, during the past two decades, a significant shift in the locus of R&D has occurred. Whereas network providers operated important research laboratories that contributed major inventions, since the 1980s the R&D intensity of network operators has diminished.[11] Much of the R&D has migrated to device manufacturers and software vendors (Fransman 2010).

[10] Throughout most of the twentieth century, Sweden held the top position with regard to ICT infrastructure availability and efficiency.

[11] Researchers at Bell Laboratories invented the transistor and made major contributions in a number of fields, including laser technology (used in fiber communication networks), mobile cellular and wireless local area technology, the C programming language, and sensor and imaging

The U.S. position in computing and components was somewhat more volatile and was successfully challenged, at least temporarily, in some areas. Japan made inroads into the semiconductor and consumer electronics business during the 1980s and other Asian countries followed in the 2000s. The U.S. regained some of its prowess in semiconductors when companies such as Motorola, Intel, and Texas Instruments accelerated efforts with Dynamic Random Access Memory (DRAM) technology. Through 2000, the U.S. share in global semiconductor sales recovered but manufacturers in the Asia-Pacific region have been able to increase their global share steadily ever since. America's position was probably least contested in software and in web applications, although even in some of these segments the competitive landscape shifted in favour of other nations. The three global leading software vendors are U.S. firms (Microsoft, IBM, Oracle) and U.S. firms hold dominant positions in search markets (Google), browsers (Microsoft, Mozilla, Google) and cloud computing. In some of these markets, open source software has captured a significant market share and foreign vendors have gained in selected national and regional markets (e.g., search engine Baidu in China). In applications and services, many innovative foreign competitors have emerged in the past 10 years. For example, European firms have been able to capture noticeable market shares in business software (e.g., SAP), browsing (e.g., Opera) and in online music markets (e.g., Deezer).

Public policy influenced the historical innovation performance of the U.S. ICT sector in multiple ways. However, as the technology and its applications become increasingly complex, future policies will be exceedingly difficult to design and implement. Software-based innovation at the edges of the network has greatly increased the combinatorial space for technological advances (Arthur 2009). Complex adaptive systems theory would suggest that diversity of public policy interventions and an institutional environment that supports public policy and commercial experimentation would stimulate innovation (Beinhocker 2006). The diversity and multifaceted nature of U.S. innovation policy, therefore, seems to be an important contributing factor. One could argue that the U.S. innovation system, in part by deliberate design, in part by serendipity, was structured in non-linear fashion long before this became recognised by the mainstream R&D policy (OECD 2005). The parallel and duplicative activities by different government agencies, the interaction between federal research laboratories, universities, and private sector

technology. Seven Physics Nobel Prizes were awarded to researchers at Bell Labs. After the break-up of the Bell System in 1984, Bellcore (now Telcordia) was spun-off from Bell Labs to produce similar research services for the newly established Regional Bell Operating Companies (RBOCs) that focused on the provision of local exchange carriers. In 1996, AT&T divested AT&T Bell Labs, integrating it into a new company, Lucent Technologies. Lucent Technologies became part of Alcatel-Lucent in 2006.As a consequence of the merger, Lucent Bell Laboratories and Alcatel Research and Innovation were integrated into a new Bell Laboratories. However, in 2008, only four physicists remained employed in basic research functions and the company announced that it would withdraw from basic research to focus on more immediately marketable areas such as networking technology and high-speed electronics.

researchers, and a culture of entrepreneurship and risk-taking generated a highly dynamic co-evolutionary system. Furthermore, during several post WWII decades, national security interests, a powerful motivating force of public policy, and high-tech innovation in ICT were mutually reinforcing. This congruence facilitated support for R&D in computing, semiconductors, networking, and software. As the Cold War receded, this parallelism also weakened. In other areas of R&D policy, for example, environmental policy, energy efficiency, and health IT, the nexus between national interests and R&D is more difficult to establish in a compelling fashion. This is illustrated in the latest fiscal policy documents by the House leadership that propose a return to purely market-driven energy policy without regard for the innovation opportunities that a more aggressive policy might open.

Whereas the very successful interaction and collaboration of government, universities and the private sector continues to show considerable dynamic, it also exhibits signs of strain. Significantly reduced military R&D spending has only partially been compensated by higher funding for the National Science Foundation and other federal institutes. Given current fiscal pressures, significantly higher levels of government spending seem out of reach for the near future. Private sector spending can be stimulated with tax incentives such as the extended F&E tax credit and simplifications of regulations affecting innovation. The goal of increasing U.S. R&D spending to above 3% of GDP seems ambitious but within reach. However, one has to keep in mind that other countries also envision increases and that the set mark is not international best practice. Another problem for the U.S. innovation system might be that the low-hanging fruit have been harvested, as Cowan (2010) argues. If indeed technical change has reached a plateau with lower rates of change and fewer innovation opportunities, higher R&D efforts may not translate into more innovation.

In ICT industries, these concerns are aggravated by three factors: (1) the shifting of production and some of the R&D to overseas locations, (2) the ease with which some software-based innovations can be imitated by competitors, and (3) the difficulty of finding sustainable business models in markets with very low incremental costs but high costs of generating a first copy of a product or service. Globalization of supply chains has weakened the domestic effects of knowledge generation. On the one hand, the production activities and jobs associated with knowledge-intensive products are often located abroad. For example, whereas Apple has manufacturing plants in the U.S. and in Europe, a very large share of its products is produced in Asia. On the other hand, after an initial design is created, many subsequent product and service innovations emerge from the practical knowledge generated in the production process (Stoneman 2010). Offshore production limits these learning effects, which may weaken longer-term innovation performance of a nation.

Innovation is in part fuelled by the ability of companies to recoup temporary innovation rents. In industries where imitation is easy, innovations may not have the same multiplier effect on production and jobs compared to industries where imitation is more cumbersome. This effect is aggravated if production is internationally mobile. In the long run the innovation rate in such industries may even be lowered. Products and services in several ICT market segments, such as software or software-based applications, can be imitated relatively easily. This is one of the reasons why intellectual property right protection has become an important issue. However, the optimal scope and duration of protection is difficult to determine and subject to considerable controversy (Jaffe and Lerner 2004). In areas where complementary skills and knowledge are important, proprietary knowledge may even diminish innovation. An increasing number of firms are therefore making some of their intellectual property available freely to others in the hope of benefiting from indirect spill-backs. In other areas, the fragmentation of intellectual property rights may create barriers to further innovation built on such knowledge. Patent thickets are often generated by firms who want to fend off competitors, but they also reduce the set of available innovation opportunities by narrowing "adjacent possibilities" for other players.

Lastly, many segments of ICT have peculiar cost structures: high costs to generate a first copy and low or even zero incremental costs. Competitive pressure in such markets will relentlessly drive market prices to incremental costs. Some firms may be able to build sustainable business models around giving away a software package or a service for free. This can be done by deriving an income stream from advertising, by bundling a free product with one that is more difficult to imitate, or by various models of price and product differentiation (Shapiro and Varian 1999; Anderson 2009). However, it must be doubted whether all firms in the ICT sector can pursue such a strategy, especially because digital technology allows unlimited copying, whether legal or illicit, that may further undermine the ability to derive a revenue stream. Thus, compared to manufacturing industries, technology and cost characteristics inherent to ICT challenge the notion that the generation of advanced knowledge and innovation will subsequently improve economic growth and employment.

5.9 Conclusions

After two decades of strong belief in unfettered markets, during which the U.S. has slipped in terms of high-tech performance, the country has begun to reshape its approach to high-tech policy. This process started under the previous Republican administration but it has become a much more concerted effort under the Obama Administration. Even during the period of high trust in unregulated markets, the government shaped private sector innovation policy in many ways. Nonetheless, the massive public funding for R&D associated with the Cold War has declined substantially, although the private sector has picked up a large part of the share. It is unlikely that similar levels of overall public funding will be forthcoming, despite strong commitments to increase resources channeled through the major federal research agencies, such as the NSF, NIH and NIST. Given the current absence of bipartisan politics and the country's fiscal problems, it is even questionable whether the Administration's innovation strategy will be funded at the desired level. The country does not lack the instruments to pursue a forward-looking high-tech innovation strategy, but rather the political consensus necessary to find feasible solutions.

Despite these handicaps, the country's entrepreneurial culture, the willingness of individuals and organizations to take risk, continues to be a strong force of economic dynamics. However, market forces alone do not channel this energy into the full range of projects that have a high payoff for the welfare of future generations, such as clean energy. In international comparison, the U.S. has not necessarily slipped back, but other nations and regions have gained – some, such as the Asian countries, with a policy mix quite different from the U.S. approach. Whereas the Anglo-Saxon model may have lost in credibility and the performance of other approaches has been respectable and occasionally even better, gradual rather than radical reform of that model with more coherently designed interaction between government, universities, and industry may be the only way forward for the U.S. in the near future. According to emerging policy visions, an important role of government is to serve as a convener and facilitator of private sector innovation networks. Although this seems to be a step in the right direction, it will likely not suffice to propel U.S. high-tech performance back to the pole position. The complexity of high-tech industries will require additional measures, such as continued research funding, support for the adoption of advanced technologies, and reform of the educational system. Most importantly, the country would benefit from an overarching framework for the continuous refinement, monitoring, and adaptation of high-tech policy.

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